

**Mechanism of Corn (*Zea mays* L.)
Response to Cropping Practices
Without Tillage**

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D. M. VAN DOREN, JR. and G. B. TRIPLETT, JR.¹

INTRODUCTION

Soil has traditionally been tilled to alter soil structure, manage crop residues, and kill undesirable vegetation. Herbicides make vegetation control possible in corn and other crops without mechanical manipulation of the soil. This circular reports recent results in no-tillage corn culture and explains corn response to the environment created by no-tillage systems.

Satisfactory no-tillage crop production practices have been described in detail (16, 19). Prior to seedling emergence, a herbicide or mixture of herbicides is applied to kill existing vegetation. The herbicide treatment must not injure the corn, must eliminate perennial vegetation, prevent germination and growth of annual weeds from seed during the active corn growing season, and should not injure succeeding crops. Fertilizer may be broadcast, placed in the row, or both.

Planting is performed with specialized equipment. The planter must be able to cut through the sod mat and fresh or dried plant debris and place the seed at a proper depth in contact with soil. It must also place fertilizer (if placed in the row) below the seed and preferably at the side. The seed must be covered to prevent rapid soil drying around the seed and seed losses to foraging animals (12, 18). No other operations should be required prior to harvest.

GENERAL YIELD COMPARISONS

Corn growth after emergence in tilled (plowed plus secondary tillage) soil is compared with growth in non-tilled soil. Factors contributing to lower stand or less complete weed control in one system or the other, although important in overall performance of the system, are unnecessary complications for this report. Therefore, data are used only from experiments having equal stands and weed control for all tillage systems compared.

Gross average corn grain yields of experiments conducted from 1960 to 1966 in Virginia (7, 8, 12, 13) and experiments conducted from 1960 to 1967 in Ohio are listed in Table 1. Virginia data were obtained by calculating the grand mean of all treatment means reported. Each

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TABLE 1.—Corn Grain Yield as a Function of Previous Crops, Soil Types, and Tillage Systems.

State	Soil Surface Texture	Previous Crop	Number of Location Years	Grain Yield (kg./ha.)		Stand (thousands/ha.)	
				Conventional Tillage	No-Tillage	Conventional Tillage	No-Tillage
Ohio	Clay loam to clay*	Row	18	6550	5890	43.3	43.3
Ohio	Clay loam to clay*	Sod	13	6610	6360	43.3	43.3
Ohio	Silt loam†	Row	24	5890	5820	43.7	44.2
Ohio	Silt loam†	Sod	16	6560	7400	44.3	43.6
Virginia	Silt loam‡	Sod	15	5170	6180	—	—

*Hoytville and Toledo series.

†Wooster, Crosby, Canfield, and Ravenna series primarily.

‡Greendale, Groseclose, and Lodi series primarily.

treatment mean used represented four or more replications. Ohio data were obtained by least squares analysis of all individual plot data. Years, locations, and replicates within a location were absorbed into the error term.

No-tillage planting of corn following a row crop on clay loam to clay soils produced lower yields than the fall-plowed conventional tillage system. Corn yields from the two tillage systems were substantially equal on the clay loam to clay soils following sod and on the silt loam soils following a row crop. No-tillage planting of corn following sod on silt loam soils produced substantially greater yields compared with the spring-plowed conventional tillage systems in both states. This apparent interaction between soil type and previous crop should be examined to establish major causes for variations in yield differences between tillage treatments.

TILLAGE RESEARCH ON SILT LOAM SOILS

Most tillage data from Ohio on silt loam soils have come from the Wooster, Crosby, Canfield, and Ravenna soil series. A typical mechanical analysis of the Ap horizon indicates 20% sand, 65% silt, and 15% clay. Organic matter averages 2.5% or less. Bulk density ranges from 1.5 g./cm.³ prior to spring plowing to 1.0 g./cm.³ immediately after plowing. Structural stability is low, as indicated by the rapid decrease in infiltration soon after the start of an intense rain on bare soil typified by infiltration data for Canfield soil in Figure 1 (15).

Post-planting cultivation of corn grown on plowed seedbeds increased average corn grain yields by 310 to 620 kg./ha. in the absence of weed competition (23). Prihar (14) indicates that the potential beneficial effects of cultivation were due about equally to increased infiltration of rainfall and to decreased evaporation or decreased mechanical impedance or both. There was no evidence that soil aeration was limiting in either cultivated or non-cultivated systems. Thus, the evidence strongly suggests that cultivation improved the soil moisture regime for corn with a consequent yield increase.

Management of surface residues by no-tillage cropping systems may be an equally or more efficient means of securing a favorable moisture balance. Mulch provided by a killed sod is expected to reduce runoff and erosion compared with plowed soil, as would the sod before being killed.

Information for no-tillage corn after corn in Ohio indicates that runoff is greatly reduced by the residue cover. Harrold (5) reports runoff and erosion from a non-tilled watershed planted to corn to be 27% and 2%, respectively, of amounts from a plowed watershed over a 3-year

period. Triplett (20) compared infiltration data from non-tilled and conventionally tilled plots after the 3rd year of continuous corn (Table 2). As the percentage of residue cover increased, infiltration rates and total infiltration tended to increase, although only the treatment with 80% residue cover was statistically greater than other treatments.

As suggested by Alderfer (2), the mechanism of residue cover effect on infiltration rate may be purely protective. The residue would physically absorb raindrop impact energy, which probably accounts for most surface structural breakdown. Or the mechanism may be related to stable soil structure developed during the 3-year association with residue cover. This is suggested by comparing treatments D, E, and B in Table 2. Differences in infiltration between treatments D and E were presumably due to protection afforded by presence of surface cover on treatment D. Differences in infiltration between treatments E and B were presumably due to the accumulation of soil stability associated with surface cover on treatment E. The total effect of surface cover on

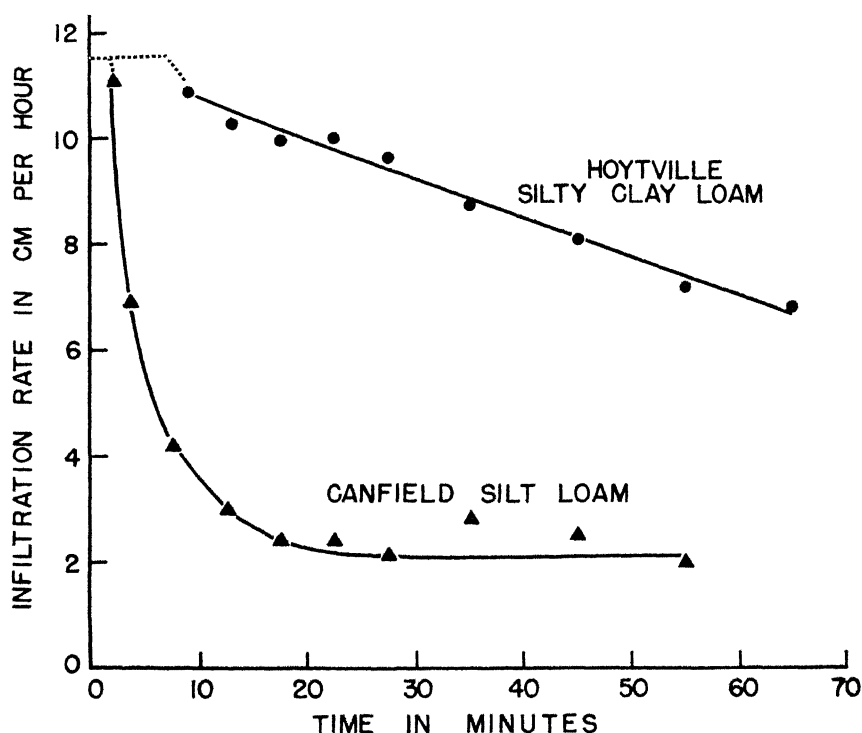


Fig. 1.—Rainfall infiltration rates into dry corn seedbeds. Rainfall applied artificially at rate of 11.5 cm. per hour. Each data point is the mean of six replicates. After Schmidt (15).

infiltration was treatment D minus treatment B. Most of this difference was caused by accumulation of soil stability.

More intensive investigation of the mechanism of mulch effect on infiltration is in progress. It is sufficient to state that mulches can appreciably increase or maintain infiltration rates on non-tilled land, despite a tendency for non-tilled soil to have greater bulk density and lower antecedent air-filled pore space than conventionally tilled soil (Table 2).

Residue cover on the soil surface may or may not influence evaporation, depending upon evaporative demand and unsaturated hydraulic conductivity of the soil (22). If conditions permit maintenance of a moist, bare soil surface, residue cover reduces evaporation (7). If conditions dry the bare surface rapidly, residue cover may have no effect on evaporation (3). A dry soil surface is evidently a greater barrier to water vapor diffusion than a residue cover and rates of evaporation from bare and mulched systems are quickly equalized.

What effect will this capacity of surface residues to increase the quantity of available soil moisture and longevity of retention in the profile have on yields from no-tillage corn culture?

Yield regression on residue cover. Relationship between the percentage of the soil surface covered with plant residues and corn yield was

TABLE 2.—Treatment Effect on Infiltration, Bulk Density, and Air-Filled Pore Space on Wooster Silt Loam Soil. All Values Are Means of Three Replications. Rainfall Applied at 11.5 cm./hr. Rate for 1 Hour. After Triplett (20).

Treatment	Antecedent Bulk Density (1.3-8.9 cm. depth)	Antecedent Air-Filled Pores (0-15 cm. depth)	Instantaneous Infiltration Rate After 1 Hour	Total Infiltration After 1 Hour
	g./cm. ³	cm.	cm./hr.	cm.
A. Plowed, disked, cultivated				
Bare soil surface	1.33a†	4.98a	0.66b	1.80b
B. No-tillage				
Bare soil surface	1.43ab	4.34b	0.28b	1.22b
C. No-tillage				
40 % residue cover	1.50b	4.04c	1.17b	2.34b
D. No-tillage				
80 % residue cover	1.46b	3.73c	2.64a	4.39a
E. No-tillage				
80 % residue cover, removed just prior to rainfall	1.46b	3.86c	2.41a	4.17a

LSD at 5 %

0.101

0.138

1.07

1.73

†Values followed by the same letter within each data class are not significantly different at the 5 % level of probability. Duncan's multiple range test.

obtained from a 6-year tillage experiment on Wooster silt loam. Eight tillage practices including no-tillage appeared each year in all possible combinations with two previous crops (corn and fescue sod) and two systems of handling plant residues from these previous crops. Corn stalks from the previous year were either cut off at the soil surface and the plots raked bare or the stalks were knocked down and left on the soil surface. Fescue leaves and stems from the previous year and early spring growth (killed with herbicides) were either mowed as close to the soil surface as possible and raked off or were left intact. Similar residue management was practiced on the plowed, cultivated treatments considered conventional tillage. All other manageable environmental factors were the same for all treatments.

Linear regressions of yield on percentage of the soil surface covered with plant residues in August or early September as measured with a point quadrat are reported in Table 3. No residue quality factor or weight of residues was obtained.

Corn yields increased about 34 kg./ha. (0.54 bu./acre) per percent of increase in soil surface residue cover. The previous crop variable had little influence on slope of the regression curves or on the degree of surface cover at which non-tilled treatments equalled yield from the conventionally tilled treatments. Visible wilting occurred several times each year on the bare, non-tilled plots, indicating that soil moisture was limiting corn growth. Slope of the regression curves would probably be different in years with more adequate rainfall. However, even if these regressions are rainfall dependent, a positive, statistically and biologically significant relationship existed between plant residue cover and corn yield for non-tilled soil.

These regression relationships help explain some of the yield comparisons in Table 1. In Ohio, the average yield on silt loam soils following a row crop was the same for both tillage systems. The average coverage of the soil surface by crop residues on the non-tilled system was 51%. This was 8% less than the coverage required for yields produced by no-tillage to equal yields from conventional tillage as predicted by regression data in Table 3. The average yield on the same soils following sod was 840 kg./ha. greater for no-tillage than conventional tillage. Residue cover following sod averaged 82% on the non-tilled system. This is 33% greater residue cover than that predicted by the regression equations for equal yields between tillage systems (Table 3).

Yields of no-tillage corn relative to yields from conventional tillage average about 600 kg./ha. more following sod than corn at equal percentages of soil cover. Sod (grass particularly) is more likely to provide a greater plant residue cover than corn. On the average, then, the

TABLE 3.—Linear Regression of Grain Yield on Percent of the Soil Surface Covered with Dead Plant Residues in August or September as a Function of Soil Texture Group and Previous Crop.

Value	Silt Loam† Previous Crop		Silty Clay Loam‡ Previous Crop	
	Corn	Sod	Corn	Sod
No-tillage yield at 0% residue cover (kg./ha.)	3660	4390	5140	6010
No-tillage yield at 100% residue cover (kg./ha.)	6960	7860	4580	5420
Average yield for plowed treatments (kg./ha.)	5610	6080	6700	6740
Regression F value from least squares analysis	62.9**	19.0**	0.1ns	0.3ns
Slope of regression (kg./ha. per 1% cover)§	+33.0	+34.7	—	—

†Data obtained from Ohio on Wooster silt loam soil from 1962 through 1967.

‡Data obtained from Ohio on Hoytville silty clay loam soil from 1966 through 1967.

§ $Y = a + bX$, where Y = corn grain yield in kg./ha., X = percent of the soil surface covered with residue, b = slope of the regression, and a = yield at 0% residue cover in kg./ha.

**Denotes significance at the 1% level of probability.

no-tillage corn yield advantage following sod is expected to be greater than that following corn.

Partition of mulch effect. Reasons for the previous crop effect shown in Table 1 have now been given for these soils. The next question is: how do plant residues on the soil surface promote greater corn growth and yield? The potential effect of residue cover was separated into infiltration and "other" components in an experiment performed in 1965 and 1966 on Wooster silt loam. The other components consisted of changes in evaporation, soil temperature, aeration, and mechanical impedance. Treatments were:

- A. No-tillage, soil surface bare, runoff allowed.
- B. No-tillage, soil surface bare, runoff not allowed by driving 10 cm. wide strips of 18 gauge metal halfway into the soil in a pattern to impound rainfall in 35 x 38 cm. "ponds".
- C. No-tillage, 100% of the soil surface covered by straw, runoff not allowed by using same strips as in B.
- D. No-tillage, 100% of the soil surface covered by straw, irrigation applied to maintain profile at or above 75% available water-holding capacity (1966 only).

Treatments B, C, and D were applied: (1) from emergence to 2 weeks before tasseling, (2) from 2 weeks before tasseling to harvest, and (3) from emergence to harvest. Fertility, plant population, rainfall, air temperature, and planting date were the same for all treatments within each year. In addition to grain yield from each plot, leaf area was estimated by the following equation:

$$LAI = \frac{\sum(0.75 \times W \times L)}{N} \times P$$

Where LAI = Leaf area index

Σ = Sum

W = Maximum width of each leaf on each plant (cm.)

L = Length of each leaf corresponding to each W value (cm.)

N = Number of plants measured

P = Number of plants per cm.²

Runoff from 1.2 m. x 1.2 m. square frames was obtained from the A treatments in 1966. Soil moisture content was measured at four depths to 90 cm. with neutron attenuation apparatus in four treatments on a once-a-week schedule in 1966. Since all treatments started at the same moisture content, the data are reported in Table 5 as changes in moisture content by volume for the specified time period.

Yield of treatment B minus yield of treatment A is corn response to the maximum potential straw-cover effect in reducing runoff from the site. No runoff occurred from treatment B because of the metal strips. This, of course, is the best that a straw mulch could accomplish in increasing infiltration. The soil surface was exposed to incoming radiation, wind movement, and raindrop impact to a similar degree in both treatments. Perhaps the metal strips reduced wind velocity slightly and shaded a small part of the soil surface, causing lower evaporation in treatment B than treatment A. The net effect is that probably the only major difference between the treatments was in quantity of infiltration.

Yield of treatment C minus yield of treatment B represents the remainder or "other" component of the maximum potential straw-cover effect on corn growth under the prevailing environmental conditions.

Of the maximum potential increase in yield associated with season-long presence of residue cover (2060 kg./ha., Table 4), approximately one-third was related to improved infiltration. Considering that only 17 mm. water ran off the check treatment during the "early" period in 1966 (49 mm. total precipitation) and only 21 mm. ran off during the "late" period (142 mm. total precipitation), it is surprising that the infiltration effect in Table 4 was so large. Different rainfall patterns may change the fraction of the total effect associated with runoff.

Two-thirds of the yield increase was related to other factors. The most logical factor would be increased moisture available to the plants due to decreased evaporation. Soil temperature reduction prior to complete shading of the soil by the corn canopy associated with mulches (10, 21) probably would not increase yield. Aeration (rate of gas in-

TABLE 4.—Corn Grain Yield as a Function of Type and Timing of Amendment Application.

Treatment Description Amendment Application					Leaf Area Index Relationships		Partition of Total Yield Increase								
					Mean Yield Relationships Yield(†) Total Increase (kg./ha.) (kg./ha.) (Prob.)‡			Mean LAI	Linear Regression	Mean Yield at LAI of Check	Yield Increase at LAI of Check		Yield Increase Due to LAI Increase		
								(kg./ha.)	(kg./ha.)	(Prob.)‡	(kg./ha.)	(kg./ha.)	(Prob.)‡	(kg./ha.)	(Prob.)‡
A. None (check)					4480 ± 118†			1.72	1263**	4480 ± 118†					
B. Runoff retarders	1) Early§	4950 ± 190†	470	P.16	1.86	1296**	4770 ± 192†	ns						ns	
	2) Late††	4710 ± 183†	ns		1.76	1483**	4650 ± 183†	ns						ns	
	3) Season‡‡	5150 ± 142†	670	P.02	1.83	1305**	5000 ± 143†	520	P.07				ns		
C. Runoff retarders + mulch	1) Early	5970 ± 239†	1490	P.001	2.17	789*	5620 ± 282†	1140	P.02				ns		
	2) Late	4820 ± 241†	ns		1.74	1127*	4800 ± 241†	ns					ns		
	3) Season	6540 ± 163†	2060	P.001	2.22	1096*	5990 ± 189†	1510	P.001			550	P.11		
D. Irrigation + mulch (1966 only)	1) Early	7280	2800		2.80										
	2) Late	5670	1190		1.74										
	3) Season	9200	4720		2.88										

†Mean yield ± confidence interval about the mean as a function of student's t. (31 degrees of freedom for the check; 13 degrees of freedom for all others.)

‡Probability level at which the yield increase [yield of treatment in question — yield of check] is greater than zero.

§From emergence to 2 weeks before tasseling.

††From 2 weeks before tasseling to harvest.

‡‡From emergence to harvest.

*Significant at the 5 % level of probability (P.05).

**Significant at the 1 % level of probability (P.01).

terchange) would not be increased by presence of residue cover since increased soil moisture content (if any) would tend to decrease aeration. Decomposition products from the mulch could stimulate corn growth, although generally these materials have reduced corn growth (9). Some secondary mechanism may be responsible for the measured potential yield increase but improved soil moisture regime appears to directly or indirectly cause the yield increase.

Most of the yield effect was concentrated in the first half of the growing season (Table 4). This is logical considering that the majority of evaporation losses should occur before the corn canopy significantly reduces incident radiation reaching the soil surface. This radiation is the prime source of energy for evaporation of moisture from the soil (17).

Increased available moisture early in the season was responsible for increased leaf area production (Table 4). Regressions of yield on leaf area index (LAI) were computed for each treatment. Average LAI of the check treatment (1.72) was substituted in each of the other equations, which were then solved for yield. Comparisons of the calculated mean yields at LAI of the check indicate that most of the total yield increase (if any) would have occurred if there had been no increase in leaf area. In other words, the increases in yields were not related to increased LAI but to greater efficiency of grain production (carbohydrate synthesis) per unit of leaf area. Increased LAI significantly improved yield only with the full potential of mulch over the entire season (C-3, Table 4).

Plants with greater above-ground growth are generally assumed to have greater root growth. Plants with greater leaf area might then be expected to have greater root development. In this experiment, perhaps the more favorable moisture regime associated with residue cover coupled with the presumably greater root development resulted in better moisture utilization and maintained more favorable photosynthetic conditions in the leaves throughout the growing season. However, soil moisture regime or something else apparently was sufficiently limiting to photosynthesis so that increased light interception by the canopy (if any) associated with the greater LAI was not translated into increased yield.

To illustrate the degree to which the above results were dependent upon the prevailing rainfall pattern, a set of irrigated treatments was included in 1966 (Table 4). Strict statistical comparisons with other data in the table cannot be made. However, the large yield differences leave little doubt that moisture was limiting on all of the non-irrigated treatments.

Without irrigation, application of runoff retarders and mulch from 2 weeks before tasseling to harvest had little or no effect on yield. Irri-

TABLE 5.—Moisture Content Changes in 0-90 cm. Profile During 1966. Starting Available Moisture Content Averaged 10.5 cm.

Amendment	Time of Application	Change Early* (cm.)	Change Late† (cm.)	Change Season‡ (cm.)
A. None (check)	—	—2.1	—6.4	—8.5
C. Runoff	1) Early*	—2.1	—6.7	—8.7
retarders	2) Late†	—1.9	—4.0	—5.9
+ mulch	3) Season‡	—1.8	—6.2	—8.0
	LSD .05	0.47	0.57	0.53

*From emergence to 2 weeks before tasseling.

†From 2 weeks before tasseling to harvest.

‡From emergence to harvest.

gation during the same time period produced a substantial yield increase. Therefore, it cannot be concluded that the existence of residue cover during the second half of the growing season would never affect yields. The potential yield effect is concentrated in, but not limited to, the first half of the growing season.

Since the main mechanisms of treatments B and C are improvement of the soil moisture regime, moisture content differences should be measurable among treatments (Table 5). Moisture changes were the same for treatments A and C-2 during the "early" period. That is fortunate because during the "early" period they were exactly the same treatment. Moisture decrease was lower for C-2 during the "late" period than for A, reflecting the expected reduction in evaporation and measured reduction in runoff. However, treatments C-1 and C-3 had moisture changes similar to treatment A during the entire season, which does not indicate any moisture regime improvement.

Leaving this experiment for the moment, Table 6 summarizes data from Virginia (11) and Ohio (20) comparing soil moisture under no-tillage plus residues and conventional tillage. During the periods re-

TABLE 6.—Mean Available Soil Moisture Content in cm. from Top 0-46 cm. of Soil Profile as a Function of Tillage Treatment.

	From Ohio (20)†		From Virginia (11)‡	
	Conventional Tillage	No-Tillage 75 % Surface Cover	Conventional Tillage	No-Tillage After Sod
June 15—July 15	5.2	7.4	6.3	8.9
July 15—August 15	3.7	5.1	2.4	3.6

†2-year average of three replicates

‡1-year average of four replicates

corded, the no-tillage treatments had more available moisture, particularly before mid-July. Yields from no-tillage in Ohio were 6620 kg./ha. compared with 5970 kg./ha. with conventional tillage, while those from the two tillage systems in Virginia were equal, perhaps due to extremely dry weather at tasseling time (stover yields in Virginia were 2100 kg./ha. greater with no-tillage).

The major problem in trying to relate measured differences (if any) is that moisture content gives only a static value, while dynamics of the moisture regime is the most important factor. The moisture content differences measured are only symptomatic and no quantitative yield relations can be placed on them. Measurements of runoff, evaporation from the soil surface, and transpiration must be obtained to adequately evaluate the effect of surface cover on the plant-soil system. For example, an important piece of information would be how much water is transpired by the crop. Evaporation from the soil surface is included in evapotranspiration estimates but such water loss does nothing to satisfy the moisture needs of the plant. If two systems have equal evapotranspiration rates, plants in the system with the higher evaporation rate are more likely to exhibit symptoms of moisture stress. This is probably what happened with treatments A, C, and C-3. All had the same rate of water loss from the soil. However, A had the greatest evaporation loss from the soil (as well as greater runoff losses) and the plants suffered greater moisture stress and produced less grain.

TILLAGE RESEARCH ON CLAY LOAM TO CLAY SOILS

Most tillage data from Ohio on these soils have come from the Hoytville and Toledo series. A typical mechanical analysis of the Ap horizon indicates 15% sand, 35% silt, and 50% clay. Organic matter averages 4 to 7%. Bulk densities range from 1.3 g./cm.³ prior to plowing to 0.8 g./cm.³ immediately after plowing. Structural stability is high, as is the tendency to form cracks upon drying. These observations are substantiated by the high infiltration rates maintained for more than an hour on a dry, bare Hoytville profile subjected to intense rainfall (Figure 1).

Post-planting cultivation of plowed seedbeds in the absence of weed competition may decrease average corn grain yields as much as 300 kg./ha. (23). Regression of yield on residue cover was obtained from a 2-year study on Hoytville silty clay loam soil with a procedure similar to that described for silt loam soils. Residue cover had no effect on yield (Table 3). Reasons for the differences in response of clay soils compared with silt loam soils have not been firmly established. Infor-

mation from clay loam soils is much less comprehensive and conclusions are necessarily more tentative.

The present hypothesis is that the cracking of clay soils would maintain high infiltration rates. Evaporation from such cracks could account for as much as 50% or more of total evaporation (1). Thus, the surface conditions including mulch cover may have little net effect on soil water balance and therefore little net effect on crop yield.

Data from Iowa (4) on similar, black, poorly drained soils and from 1 year of measurements on Hoytville soil in Ohio indicate a good mulch can depress average daily soil temperatures by 2° C. at 10 cm. depth. Early corn growth (first 48 days) was reduced from 14 to 67% compared with bare, plowed treatments. Final grain yield was 18% less on the mulched treatment in the Ohio test. Yield data were not presented for the Iowa case. Perhaps early growth reduction due to lowered temperatures was not compensated later by improved moisture regimes. This could account for the differences in response to residue cover on non-tilled systems between the two soil groups.

SUMMARY

Grain yield response (if any) to no-tillage corn culture systems is primarily related to soil moisture regime, assuming adequate weed control and plant populations are achieved. On soils exhibiting low structural stability and which do not form deep cracks on drying, plant materials on the soil surface improved yields approximately 34 kg./ha. for each additional 1% of the soil surface covered. The mechanism of yield increase was associated with increased infiltration and decreased evaporation, with the effects concentrated in the period preceding tasseling. On soils with stable structures which form large cracks on drying, such surface cover had no effect on yield.

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